Third Party Effects and Asymmetric Externalities in Groundwater Extraction: The Case of Cherokee Strip in Butte County, California

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1. Overview

1.1 Introduction

Common Property regimes are well-studied in the economic literature, due to the externalities that typically are typically imposed on users of the resource and the difficulty of regulation and enforcement (Hardin, 1968; Gordon, 1954). These externalities arise from over-exploitation of the common-pool resource by users, who typically have unrestricted access to it, and consider only their own private benefits when deciding how much of the resource to exploit (Scott, 1954; Dasgupta and Heal, 1979). Regulation is often required due to the difficulty of realizing decentralized Coasian bargaining, either due to the presence of transactions costs, asymmetry in information (Farrell, 1987), scale considerations (Nalebuff, 1997) or other reasons.

Groundwater is a frequently over-exploited common-pool resource for irrigated agriculture, and its depletion, in numerous cases that have been studied, has led to serious conflicts between users (Ostrom, 1990). Some of these conflicts over common-pool groundwater resources have arisen as a result of disputed third-party impacts resulting from policy-promoted water transfers, such as those made to the California Emergency Drought Water Bank (Hanak, 2003) or for other voluntary market transactions (Murphy et al., 2003). While the State Water Bank was initiated with the understanding that third-party interests would be observed and adequately protected (Thilmany and Gardner, 1992), the majority of the impacts resulting from the water transfers to the Drought Bank were borne by the groundwater basin, causing third-party impacts on the local economies (resulting from sale of surface water rights) to be substituted for third-party impacts on groundwater users (Howitt, 1993a). As an illustration of this effect, nearly 37% of the increased depletion of groundwater in the Lower Cache Unit of Yolo County was attributable to transfers made to the Water Bank in 1991 (McBean, 1993).

Increased competition for groundwater resources arose in Butte County, California, as a result of water transfers made in 1994 to the State Drought Water Bank by users of surface water supplies in the county. The resulting change in the pattern of groundwater pumping in the down-slope regions of Butte County, caused irrigated agriculture in the upslope areas to be compromised, despite the presence of legal restrictions that stipulate limits on groundwater withdrawals (Thomas, 2001). In this case, sales of rights to surface water from Lake Oroville to the State Wide Drought Water Bank led to an increase in groundwater withdrawals used largely for rice irrigation by Butte county farmers on the valley floor. As a result, these compensating withdrawals imposed externalities on upslope groundwater users, in an area called the Cherokee Strip, and caused the failure of some wells in that region (Hanak, 2003).

We can gain insight into the Butte County case, as well as into other cases in which competitive groundwater extraction imposes externalities on other users, by referring to several important papers that have applied the theory of dynamic games to groundwater exploitation. All the dynamic game applications to groundwater extraction, however, have only considered the perfectly symmetrical case, in which the externalities arising from competitive pumping of the groundwater aquifer are symmetrically imposed on all users of the resource (Negri, 1989, 1990 ; Provencher and Burt, 1993; Gardner et al., 1997; Rubio and Casino, 2002) – and have ignored the possibility of asymmetric external effects. Asymmetry has implications beyond just the homogeneity of preferences and technologies of the resource users, and can also arise from the differential access that users have to the resource, given the physical relationships governing the flow of the groundwater aquifer and its disposition relative to the ground surface. This is the type of asymmetry that we address, specifically, in this paper.

The case of Cherokee Strip in Butte County illustrates the importance of asymmetric effects, and how the hydrology of the groundwater basin can prevent the strategic pumping behavior of one group of groundwater users from being fully reciprocated by another group of users. While there was an ordinance passed in 1996 to restrict the export of surface water resources from Butte County, in reaction to the effects suffered in 1994 (Thomas, 2001; Hanak, 2003), there has been little work done on making specific policy recommendations that could mitigate or avoid such an event, especially in the light of asymmetric hydrological relationships that might exist. In this paper, we go farther, by directly incorporating asymmetry into the dynamic game, and using the results to design specific policy measures that can address the problems faced when the effects caused by over-exploitation of common-pool resources are not shared equally among the players involved.

The aim of this paper is to contribute to the literature on water management policy by examining an empirical example of asymmetric externalities arising from competitive groundwater pumping. Within the context of Butte County, we examine the potential gains of imposing groundwater management and the kind of policy instruments that would be most effective in realizing these gains. Through this exercise, we gain useful insights into how asymmetrically imposed externalities might be addressed through policy intervention in other groundwater basins, as well as in other common-pool problems, more generally.

In the rest of this paper, we describe the model used to characterize water use behavior in the Cherokee Strip and lowland areas adjacent to it, and evaluate the impacts of several policy alternatives on groundwater pumping patterns and the long-run equilibrium level of the groundwater stock. From this analysis we will be able to draw a series of recommendations with which to conclude the paper.

2. Empirical Policy Analysis of Butte County

In order to explore the scope for policy intervention in the Butte Basin, we first construct a model of ground and surface water usage that is calibrated to the agricultural water demands of farmers in the basin. The derived demands are obtained by parameterization of an agricultural production model, which reflects the cropping patterns of farmers in the lower-lying and high-lying regions of Butte County. The model chosen is the Statewide Agricultural Production (SWAP) model was developed to analyze the impacts of statewide water allocation changes on California's agricultural production (Howitt et al., 2001). The demand relationships that are derived from it are shown below.

$$\begin{aligned} &\mathit{Downslope}: \quad p = 25.547 - 0.0238 \cdot q \\ &\mathit{Upslope}: \qquad \log(p) = 5.917 - 0.7514 \cdot \log(q) \end{aligned}$$

and are represented by the curves shown in Figure 1. From this figure, we see that the demand curve for the down-slope agricultural region is more elastic and is displaced to the right of the demand curve for the upslope farmers.

By using these derived demand relationships, we specify the objective function of the two 'players', by integrating under these curves. This method of obtaining annual benefit functions for water by parametric programming has been used in numerous groundwater studies (Burt, 1964; Gisser, 1970; Gisser and Mercado, 1972; Gisser and Sanchez, 1980; Feinerman and Knapp, 1983; Worthington et al., 1985; Provencher and Burt, 1994; and Knapp et al., 2003). These total surplus measures will be used to specify the benefit functions of the agents pumping

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from the aquifer and using the surface water allocations, and will be embedded in the dynamic models that compare non-cooperative pumping behavior to optimal usage.

2.1 Optimal Management of Butte Groundwater Basin

In order to establish a benchmark for economic efficiency, we construct a model of centralized water management for a simple, two-cell representation of an aquifer – one cell which represents the low-lying parts of the basin, while the other characterizes the higher-lying regions. The solution to this model represents the optimal dynamic path chosen by an omniscient ‘central planner’, who is able to observe all of the relevant variables and to exert complete influence over the water usage decisions of both the upslope and downslope regions. The economic superiority of this optimal solution over the non-cooperative pumping outcome lies in the fact that the fictional ‘central planner’ is able to internalize the externalities that are generated by pumping, such that the trade-off between upslope and downslope benefits is optimally chosen, and maximizes the joint net benefits of the entire sub-basin unit being studied.

In the case of the two-cell aquifer, a central planner would jointly maximize the net benefits of both players, by solving the following dynamic problem

$$V^{CP}\left(H_1,H_2\right)=\max_{q_1^p,q_2^p,w}\left\{\begin{array}{l} \quad B_1\left(Q_1,w\right)-e\left(G_1-H\right)Q_1-p_{sw}w \\ +B_2\left(Q_2\right)-e\left(G_2-H\right)Q_2 \\ +\mathrm{b}\cdot V^{CP}\left(H_1^+(Q_1,w),H_2^+(Q_2)\right) \\ s.t. \\ \quad Q_i=\sum_{p=1}^{3}q_i^p,\ q_i^p\le\bar{q}_i,\ q_i^p\left(H-\bar{H}_i^p\right)\ge 0 \qquad \forall i,p \end{array}\right\}$$

By solving this Bellman equation for each period of the planning horizon, the central planner achieves a dynamically-efficient and socially optimal long-run path of conjunctive ground and surface water usage. We denote the aggregate pumping activity of each player as $Q_i\left(=\sum_p q_i^p\right)$, and allow the same conditions on pumping capacity and pumping depth to hold for both agents.

2.2 Optimal Management of Butte Groundwater Basin

By calculating the difference in net benefits between the Central Planner's solution and that of the non-cooperative extraction path, we see from Table 1 that we obtain appreciable gains to management. The results in Table 8 also show a comparison between the central planner's solution and the decentralized solution of non-cooperative and completely myopic players, who optimize only their immediate benefit in each time period, according to the following criteria

$$\max_{\{q_1^p\},w} \left\{ B_1\left(\sum_{p=1}^{3} q_1^p, w\right) - e\left(G_1 - H_1\right)\sum_{p=1}^{3} q_1^p - p_{sw} w \right\}$$
$$s.t. \quad q_1^p \le \bar{q}_1, \quad q_1^p\left(H_1 - \bar{H}_1^p\right) \ge 0 \quad \forall p$$

$$\max_{\{q_2^p\}} \left\{ B_2\left(\sum_{p=1}^{3} q_2^p\right) - e\left(G_2 - H_2\right)\sum_{p=1}^{3} q_2^p \right\}$$
$$s.t. \quad q_2^p \le \bar{q}_2, \quad q_2^p\left(H_2 - \bar{H}_2^p\right) \ge 0 \quad \forall p$$

This represents individual players have no value on the stock of water that remains in the next period and, essentially, solve a static optimization problem in each period.

From the results in Table 1 we see that the percentage gains to centralized management, when measured against the dynamic game equilibrium, are uniformly smaller than those measured with respect to the path of myopic surface and groundwater usage. This corroborates the results obtained by Dixon (1991), who found that the loss in efficiency due to myopia was far greater than that due to non-cooperative and strategic behavior by dynamically-optimizing agents, and echoes the opinions of others who conclude that most of the gains to centralization can be realized by strategically and dynamically optimizing agents, but will dissipate as more players enter the game (Negri, 1989; Provencher and Burt, 1993). For the rest of the analysis we will consider the myopic, non-cooperative extraction case, as the alternative to the central planner's solution.

In order to evaluate the gains to centralized management under varying hydrological conditions, the potential recharge to aquifer was reduced by two-thirds to simulate drought conditions, and the gains to management were re-calculated for the single-cell and two-cell aquifer models. A two-thirds reduction in recharge is a reasonable simulation of drought conditions, given that the historical fluctuations in the water table has been observed to more than double in size during drought periods (Butte Basin Water Users Association, 2004). These results are presented in Table 2, with respect to myopic behavior, and show an increase in gains under drought conditions, which suggests that there is greater scope for basin management under precisely those conditions in which a State Water Bank is most likely to operate – namely, those of a drought. The increase in gains for the upslope player is appreciable as we move from normal aquifer conditions towards that of reduced recharge, which suggests that the effects of asymmetry are more keenly felt under drier conditions in the aquifer.

3. Policy Analysis for Butte County

3.1 Evaluation of Policy Instruments

In this section we explore the efficacy of three policy instruments that are aimed at mitigating the asymmetric externalities that are imposed on the up-slope player by the actions of the down-slope player. As a base case, we will consider the scenario where water sales are allowed up to the contracted amount of surface water sales to the State Drought Water Bank in

1994, by Richvale and Western Canal Water Districts (Thomas, 2001). In this scenario, the surface water price is increased from $37/acre-foot to $125/acre-foot, to reflect that average prevailing surface water purchase prices offered by the Water Bank in 1994, and both players are allowed to pump competitively and up to their respective capacities, at the prevailing energy costs for pumping.

The first of the three policy alternatives that we consider is the placement of a limit on SW sales for the downslope player, so as to allow him to sell surface water only up to 90,000 acre-feet – which is a 22% reduction in the contracted amount sold in 1994. The second policy considered is the imposition of a per-unit-volume groundwater pumping tax on the downslope player, for any quantity in excess of the historical average of pumping, prior to the operation of the water market. The pump tax is fixed at an amount that is roughly 3 times the normal pumping cost at the initial depth to water ($1.50 per acre-foot). The third policy instrument is the imposition of a limit on groundwater pumping, which restricts the downslope user to pump no more than 60% of the allowable sales (of 115,000 ac-feet) to the Water Bank.

3.2 Results of Policy Analysis and Discussion

The results of our policy analysis, under the alternative scenarios described in the previous sub-section, are given in Table 3 for the single-cell and two-cell models under different hydrological conditions and under both myopic and strategic, non-cooperative extraction behavior. The percentage gains presented in these tables are calculated from a base amount which reflects the non-cooperative and decentralized allocation without any policy intervention – the "do-nothing" scenario – under either myopic or dynamic behavior. So the gains (or losses) in those tables represent how much better (or worse) the resulting stream of net benefits become with policy intervention, under a non-cooperative and decentralized allocation, as opposed to without any intervention at all.

In Table 3, we see that the only policy that generates positive net gains, overall, is number 3, which directly limits the groundwater pumping of the downslope player to 60% of surface water sold, thereby limiting potential substitutions. In Table 3, the performance of the 'best' policy (#3) improves as hydrological conditions worsen, along with that of the groundwater tax policy (#2). The performance of the 'worst' policy, namely that of limiting surface water sales (#1), worsens with hydrological conditions, which suggests that under drought conditions – which is when water sales are most likely to occur to a Drought Bank – the worst action to take would be that of limiting exports. From these results it would be better to limit the substitution of groundwater that would occur after a sale, rather than to limit the sale itself.

In Table 4, we examine the distribution of benefits to the upslope and downslope players, under the favored policy, which is that of limiting groundwater pumping (#3). From the results shown in Table 4, we can see that the percentage gains to the upslope player are quite large under the single-cell model and remain substantial within the two-cell model, as well. The rather small (but positive) gains for the downslope player occur, despite the fact that his ability to substitute additional groundwater pumping for sales are limited by the policy. This arises from the fact that the limit on groundwater pumping prevents the marginal pumping costs from rising as fast as they would if substitution were unlimited – for both players – and this gives an indirect benefit to the downslope player, who is still able to sell his contracted amount to the Drought

Water Bank at the increased price, and use the remainder of his surface water allocation for irrigation[1].

Given that the water users in Butte County adopted an ordinance in 1996 that was aimed at restricting the future exports of surface water from the region (Thomas, 2001; Hanak, 2003), the results in Tables 3 and 4 are particularly pertinent, as they show that such a policy is a clear 'loser', in terms of overall efficiency gains. Such a policy, which limits the volume of surface water transferred, is much easier to enforce than one which limits the volume of groundwater pumped, as it is much easier to observe surface water transfers and contracts for deliveries to the State Drought Water Bank, than to monitor aggregate groundwater withdrawals. The enforcement of a tax policy would also require the measurement of individual per-period volumetric withdrawals for the purposes of per-unit taxation, and would have similar observability problems as that of monitoring and enforcing volumetric limits on groundwater pumping.

In considering possible institutional arrangements that might allow for more cooperative and coordinated behavior among water users, policy-makers must weigh the potential gains to these policy alternatives against the costs of implementing the institutional framework necessary to implement them. This is a conclusion that has been reached by several authors in the groundwater management literature, most notably Gisser and Sanchez (1980), Nieswiadomy (1985) and Knapp et al. (2003), and is often used as an argument against the establishment of complex schemes of coordinating usage of common-pool resources (Ostrom, 1991; Challen, 2000). This is the most likely reason why the adoption of local ordinances, such as that issued in 1996 in Butte County, is the most common recourse that water users take, given the relative ease

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[1] The reader should note that while surface water is sold to the Drought Water Bank at the elevated price, the surface water user is still able to obtain her entitlement at the normal per-unit cost of $37 per acre-foot.

of mobilizing local political support and voter sentiment, even though it may not be the policy that best promotes efficiency gains.

While it is beyond the scope of this paper to go deeply into the political-economy of local political action in the management of common-pool resources, it is worth pointing out that such ordinances also serve to assuage the concerns that local voters have about equity and the perceived dis-proportionality of water consumption by urban dwellers in the Southern regions of California, which can outweigh efficiency considerations in the decision-making that takes place at the local political level. A history of somewhat unscrupulous schemes to transfer water to meet the needs of growing cities in California's past, such as the buyout of land (and its accompanying water rights) in the Owens Valley, has continued to discolor the view of many farmers and water users associations against market operations aimed at benefiting urban centers (Haddad, 2000). As Haddad further points out, public goodwill was maintained in transfer agreements between Palo Verde and Imperial Irrigation Districts due to the transparency, broad participation and perceived equity of the contract terms.

An alternative to compensating for sold surface water rights through groundwater substitution by the downslope players, is that of fallowing irrigated acres. Since it was not a part of the contract exercised in Butte County in 1994, we have not discussed it in this paper. Nonetheless, it might be an alternative that could be considered in further work, by comparing the impacts on the local economy through loss of irrigated acres and production-related activities, to that of 3rd-party groundwater impacts. This would have to be done within an economy-wide model that could capture the effects that Howitt (1993b) noted in Solano and Yolo counties, as a result of Water Bank-related transfers, and which could address the concerns of local governments and interest groups cited by Haddad (2000). The gains of such a policy would not be clear unless one carefully weighed the mitigation of overdraft, subsidence and 3rd party affects associated with groundwater substitution, against the local economic impacts, the potential for increased salinity (through higher water tables) and the loss of important vegetation to the habitat and wildlife through fallowing practices.

In these results, the benefits of policy intervention to the upslope player increase during the drought years which, coincidentally, are the very years under which water transfers are most likely to occur, and in which the 3rd party groundwater users are most vulnerable. Furthermore, the results remained consistent, regardless of whether the assumption of myopic or dynamically-strategic behavior was invoked.

4. Conclusions

In this paper, we constructed a theoretical framework in which to analyze the impacts that occurred to groundwater users in the Cherokee Strip area of Butte County, as a result of sales to the Drought Water Bank in 1994. While many authors in the water resources literature have discussed the externalities of strategic groundwater pumping, none have considered cases in which the externalities imposed by competitive pumping cannot be equally reciprocated. From the empirical results of this paper, we have seen that the overall efficiency gains are consistently positive for policy which places a volumetric limit on groundwater pumping in downslope areas, so as to limit the substitution of water sold to the Drought Bank.

While the action taken by the local Butte Basin Water Users in passing a local ordinance to restrict surface water exports, is the most politically attractive and expedient one for local groundwater users to take, it may not be generating the economic gains that could be realized under the pumping limit, policy. Many economists would argue that limits on surface water exports would reduce the benefits of engaging in market-based transactions that facilitate mutually-beneficial trades between water users (Horbulyk and Lo, 1998; Hanak, 2003). By re-designing the transfer contracts with the Drought Bank, allowances for groundwater substitution could be limited, in favor of fallowing acres previously irrigated with transferred water rights. A full consideration of this alternative, however, would require a broader economy-wide analysis to measure the potential impacts of fallowing, which remains beyond the scope of this paper. Nevertheless, this paper has demonstrated the utility of adopting more realistic representations of groundwater hydrology in resource economics models, as suggested by Brozovic et al. (2003), and has added an important dimension to the current literature on strategic behavior in groundwater exploitation by taking an empirical approach that incorporates the asymmetric external effects of non-cooperative resource extraction.

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Appendix : Figures and Tables

Figure 1: Derived Water Demands for Upslope and Downslope Regions

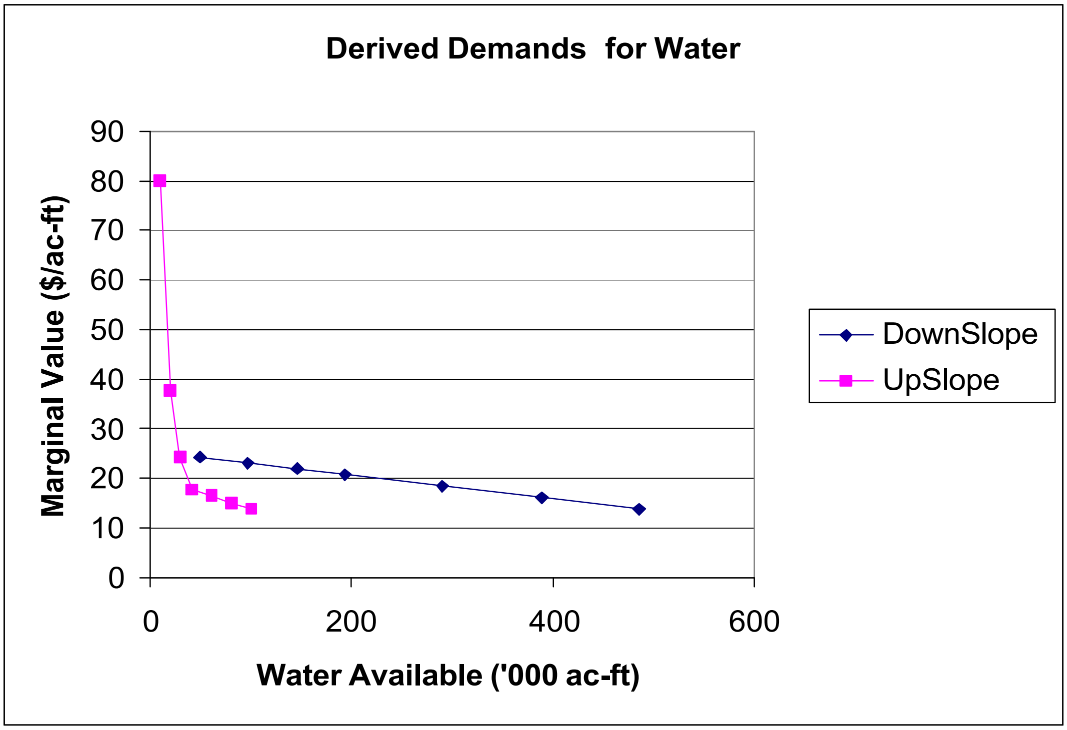

Table 8: Gains in Cumulative Net Benefits to Adopting Centralized Management of Surface and Groundwater over Non-Cooperative Allocation

Aquifer Model	Total % Gain from Centralization	% Gain for Downslope Player	% Gain for Upslope Player
	Myopic and Non-Cooperative Behavior		
Single-Cell	4.45	5.17	1.84
Two-Cell	2.87	2.86	2.89
	Dynamic and Non-Cooperative Behavior		
Single-Cell	2.47	2.86	1.03
Two-Cell	1.70	2.06	0.36

Table 9: Comparison of Gains in Cumulative Net Benefits to Adopting Centralized Management under Normal and Drought Conditions for Myopic Agents

Aquifer Model	Total % Gain from Centralization	% Gain for Downslope Player	% Gain for Upslope Player
	Normal Aquifer Recharge		
Single-Cell	4.45	5.17	1.84
Two-Cell	2.87	2.86	2.89
	Reduced Aquifer Recharge under Drought		
Single-Cell	4.60	4.70	4.10
Two-Cell	3.80	3.94	3.30

Table 11: Total Net Gains From Policy Intervention with Non-Cooperative and Myopic Agents

	Policy Instrument	Single-Cell Aquifer Model	Two-Cell Aquifer Model
	Normal Aquifer Recharge		
(1)	Limit SW Sales to 90 kAF	-1.06%	-1.19%
(2)	Tax on GW Pumping (Downslope)	-0.57%	-0.57%
(3)	Limit on GW Pumping (Downslope)	+4.99%	+1.41%
	Reduced Aquifer Recharge under Drought		
(1)	Limit SW Sales to 90 kAF	-1.24%	-1.24%
(2)	Tax on GW Pumping (Downslope)	-0.11%	-0.09%
(3)	Limit on GW Pumping (Downslope)	+5.32%	+1.73%

Table 13: Distribution of Gains under Groundwater Limit (Normal Aquifer Recharge)

Aquifer Model	Total % Gain in Net Benefits over No Intervention	% Gain for Downslope Player	% Gain for Upslope Player
Single-Cell	4.99	0.64	20.86
Two-Cell	1.41	0.52	4.79